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METROPOLITAN BOSTON AREA EARTHQUAKE LOSS STUDY

LOSS ANALYSIS COMMITTEE REPORT

and

RECOMMENDATIONS

submitted to

Robert J. Boulay, Director

Massachusetts Civil Defense Agency

February 1990

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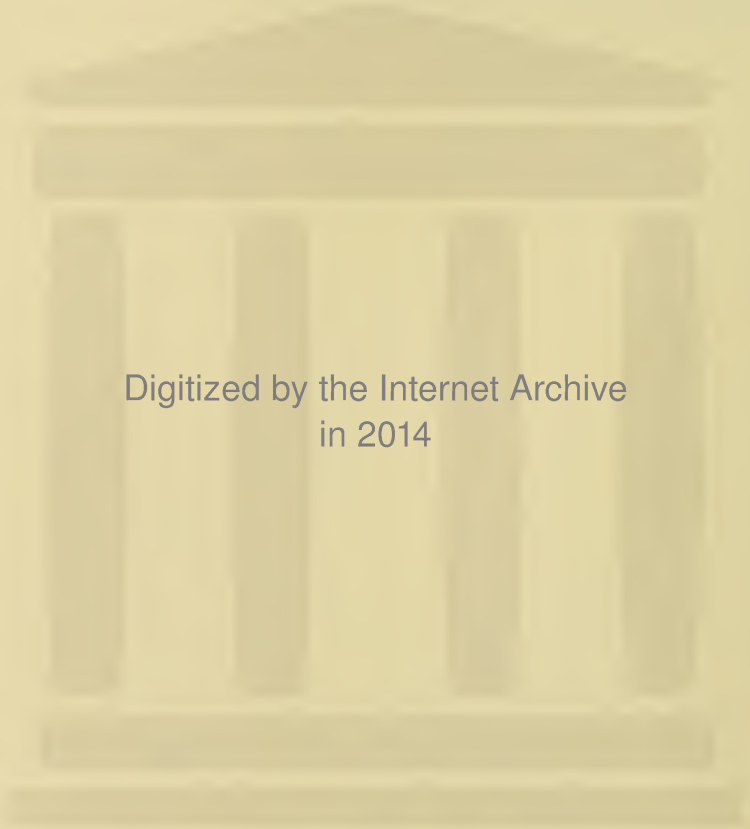

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Executive Summary

A Committee of experts established by Robert J. Boulay, Director of the Massachusetts Civil Defense Agency (MCDA), has analyzed the potential for damage to the Boston Metropolitan area from a potential earthquake. This Committee, the Seismic Loss Analysis Committee, was comprised of widely respected engineers, seismologists, and emergency managers. The primary task of the Committee was to review the Metropolitan Boston Area Earthquake Loss Study (hereinafter referred to as "the Loss Study"), prepared for MCDA by URS Consultants, Inc./John A. Blume & Associates, Engineers (hereinafter referred to as "URS").

The Committee's review of the Loss Study indicates that:

1) The occurrence of a Richter magnitude 6.25 earthquake off Cape Ann, Massachusetts, a moderate size earthquake which has already occurred in the historic record, but which may not represent either the largest earthquake that could occur in New England or its nearest possible location to the Metropolitan Boston area, would cause damage in the range of 2 to 10 billion dollars (with the best estimate being 5 to 6 billion dollars) in the Boston metropolitan area (within Route 128) due to ground shaking, with significant additional losses due to secondary effects such as soil liquefaction failures, fires, and economic interruptions. Hundreds of deaths and thousands of major and minor injuries would be expected due to such an earthquake. Thousands of people could be displaced from their homes. Significant loss of functionality in some critical facilities such as emergency public facilities, radio and TV stations and medical facilities is also expected. Additional damage may also be experienced outside the Route 128 area, especially closer to the earthquake epicenter.

2.) The potential for major damaging earthquakes exists throughout New England, including a potential for earthquakes larger than that analyzed in the Loss Study. Because of its concentrated population, and its building types and construction, the Boston area would probably suffer the most damage from an earthquake whose epicenter was in or near Boston. However, other cities throughout New England could suffer proportionately similar catastrophic damage from an earthquake epicentered in proximity to them.

3) There are low cost but effective public education, mitigation and emergency preparedness measures that can and should be carried out. These measures can reduce the loss of lives and property when an earthquake occurs in New England.

4) While this study constitutes a useful starting point, additional research in a number of technical areas would be extremely useful in the effort to understand and reduce the effects of a large earthquake in New England.

5) In view of the magnitude of the potential problem, MCDA should continue its effort to obtain state matching funds so that Massachusetts can resume its full participation in the federal Earthquake Preparedness Program.

We believe that the publication and implementation of this Committee's Report and Recommendations is a suitable beginning of New England's efforts to support the United States commitment to plan for and mitigate the results of natural hazards during this, the International Decade for Natural Disaster Reduction.

I. Background on Report and Recommendations

This Report is in response to a request made by Massachusetts Civil Defense Agency (MCDA) Director Robert J. Boulay to have the Loss Analysis Committee review, summarize and critique the Metropolitan Boston Area Earthquake Loss Study (the Loss Study) prepared by URS Consultants, Inc./John A. Blume & Associates, Engineers (hereafter referred to as "URS"). This Loss Study was commissioned by MCDA in cooperation with and utilizing funds provided by the Federal Emergency Management Agency (FEMA). The Loss Study was designed to obtain essential data to assess the potential earthquake-related loss of life, injuries and damage to lifelines/infrastructure, critical facilities, and other public and private structures within the study area from an earthquake similar in size and strength to the largest known earthquake experienced in the Boston area. This study is the result of a recommendation made by the Seismic Risk Analysis Subcommittee[1] in its final report, The Seismicity of New England and the Earthquake Hazard in Massachusetts (December 1981), and incorporates the findings of that report. The Loss Study was commissioned to provide basic information required by MCDA and FEMA to formulate state and local earthquake disaster preparedness plans and to support earthquake hazard reduction measures.

II. Overview of Earthquake Hazard in New England

Both historically and in recent times earthquakes have been felt in Massachusetts which have been centered throughout all of New

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[1]Subcommittee members: M. Nafi Toksoz, Chairman (M.I.T.), Patrick J. Barosh (Boston College), Adam Dziewonski (Harvard Univ.), John E. Ebel (Boston College), George Klimkiewicz (Weston Geophysical Research, Incorporated), Gabriel Leblanc (Weston Geophysical Research, Incorporated), Jay J. Pulli (M.I.T.) and Eugene Williams (S.M.U.)

England and the middle Atlantic states, as well as in southeastern Canada. The historic earthquake record for New England dates back to the very first explorers of North America, indicating that earthquakes have occurred/been felt in Massachusetts regularly throughout history. In New England the strongest known earthquakes occurred in 1755 off Cape Ann in Massachusetts; in 1727 near Newburyport, Massachusetts; in 1904 near Eastport, Maine; and in 1940 near Ossipee in north-central New Hampshire. Recent strong earthquakes in southeastern Canada, including the 1982 events in central New Brunswick and the 1988 earthquake in central Quebec, indicate that strong and potentially damaging events can be centered anywhere in our region.

Since 1938 the magnitudes of instrumentally-recorded earthquakes in New England and vicinity have been determined using the standard Richter technique. However, it is also possible to estimate the Richter magnitudes of older earthquakes for which no instrumental recordings exist. As a rule, the larger the earthquake the stronger the shaking at the epicenter and the larger the area over which the earthquake is felt. By studying modern earthquakes it is then possible to relate the strength of the epicentral shaking and the felt area to the Richter magnitude of an earthquake and to use these relationships to estimate the magnitude of historic shocks. Using this method, seismologists estimate the magnitudes of the largest known earthquakes in New England to have been approximately 6.0 for the 1755 Cape Ann, MA event; 5.8 for the 1904 Eastport, ME event; 5.5 and 5.4 for the 1940 Ossipee, NH events; and 5.5 for the 1727 Newburyport, MA event.

To calculate its loss estimates, this Loss Study uses the earthquake identified by the Seismic Risk Analysis Subcommittee in its final report, The Seismicity of New England and the

Earthquake Hazard in Massachusetts as its base event. "For the sake of conservatism,"[2] the Subcommittee estimated a seismic event of a magnitude somewhat greater than the largest event in the historical record as a reasonable basis for preparing an estimate of earthquake losses. This is considered a reasonable estimate; however just outside New England shocks of a Richter magnitude of 6.6 or more have taken place in the Charlevoix area of southern Quebec; and further down the east coast at Charleston, South Carolina, an earthquake of Richter magnitude 7.1 took place in 1886, heavily damaging the city and its surroundings. Detailed geological and geophysical studies of the Charleston area have failed to find a unique geological feature to which that earthquake can be attributed, but have confirmed the occurrence of several earthquakes of such magnitude in the past few thousand years. Consequently most seismologists and the U.S. Geological Survey believe that an earthquake of at least that magnitude could be possible anywhere along the seismically active eastern seaboard, including New England. Therefore, it is important to note that although the Loss Analysis Committee chose to postulate for this Loss Study a recurrence of the Cape Ann earthquake with only a slightly greater Richter magnitude of 6.25, that event may not necessarily represent the largest possible earthquake that could affect New England. It should further be noted that earthquakes are randomly occurring phenomena, and that an earthquake of a magnitude similar to this could probably occur anywhere in New England. Were this event postulated to be epicentered closer to the Metropolitan Boston study area, or closer to any major New England metropolitan area (Providence, Hartford, Portland, etc.) the amount of damage would also be quite high and the damage estimates might be higher than those given in the loss study.

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[2] The Seismicity of New England and the Earthquake Hazard in Massachusetts, Dec. 1981, p. 12.

Sections III, IV, V, and VI which follow represent the Committee's summary and commentary on the URS Study.

III. Summary of Loss Study Purpose, Scope and Methodology

Purpose and Scope of URS Loss Study: The purpose of the URS Loss Study is to estimate the physical damage, casualties and loss of functionality (i.e., ability of structures to perform/function at pre-earthquake levels) of critical facilities within the city of Boston and the surrounding 30 municipalities (listed in the table on Attachment 1) resulting from a 6.25 magnitude Cape Ann event (see Attachment 1-A). The Loss Study was commissioned to provide a basis for earthquake preparedness and response planning and as such places special emphasis on critical facilities such as medical facilities, transportation systems, utilities, communication systems, residential buildings, dams, emergency public facilities, hazardous material sites, schools, high rise buildings and critical industries. The Loss Study is concerned with areawide losses to large numbers of buildings and facilities. Consequently the loss estimates it furnishes, while providing a realistic assessment of the consequences of a Richter magnitude 6.25 Cape Ann earthquake to metropolitan Boston, are not applicable to individual sites or facilities. Such site-specific earthquake loss studies for individual facilities require detailed engineering examinations of both the sites and the structures considered, and are neither necessary nor feasible for a study of this scope.

Methodology for Loss Study: In an areawide study such as this the emphasis is on sampling techniques, expert opinion, previous earthquake damage data and statistical and probabilistic methods, as opposed to site-specific studies which enjoy more detailed

geologic, seismologic and structural evaluations. The methodology (i.e., the formula used to produce their results) used by this earthquake loss study employed five (5) basic components: an identified seismic hazard, a classification system, an inventory, a determination of structural fragilities, and an earthquake loss model.

The flowchart shown in Attachment 2 shows how these components combine to yield estimates of damage, loss of functionality, and casualties. Essentially, the methodology components are:

1) SEISMIC HAZARD: The Loss Study uses the Modified Mercalli Intensity (MMI) Scale, which provides a simple, approximate relationship between the severity of seismic shaking and damage to structures to gauge the seismic hazard (see Attachment 3 for an abridged MMI scale). The Loss Study postulates a magnitude 6.25 earthquake with an epicenter similar to that estimated for the 1755 Cape Ann earthquake. MMI values in the Boston area resulting from this earthquake were determined using an intensity-magnitude-distance formula provided by members of the Seismic Risk Analysis Subcommittee which was based on a study by Klimkiewicz et al (1982)[3], of recent earthquakes in and near New England. Based on maps of the soil types in the study area prepared by Haley and Aldrich, Inc., under a previous and separate contract, these MMI values were then modified to account for the effects of soil on ground shaking (i.e., ground shaking will be higher in areas of soft soil or fill, lower in areas of stiff soils or bedrock). The Loss Study determines MMI values of V, VI and VII to be the predominant values expected in the study

[3]Klimkiewicz, G.C., Leblanc, G., and Johnston, J., 1982, Reassessment of ground motion attenuation models for the Northeast, Earthquake Notes, Vol. 53, No. 3, pp. 23-24.

area from the postulated earthquake.

2) FACILITY CLASSIFICATION: Although every structure responds to an earthquake differently, the scope of areawide studies such as this requires grouping structures together in fairly broad classes whose overall response is expected to be similar based on those engineering characteristics most significant in determining possible earthquake damage: construction material, engineered load-resisting system, age and size (i.e., low-rise wood frame structures of recent construction will perform better and suffer less damage than 100-year-old medium-rise unreinforced masonry structures). Using these criteria, the Loss Study divides the Boston Metropolitan Area's diverse building stock into 24 different engineering classifications. By combining these classifications with the expected MMI intensity of ground motion and the estimated level of structural fragility (see 4, below), the amount of damage and loss of functionality is estimated. The same building/structure stock is then categorized by social function (e.g., hospital, school, highway, etc.). The social function classification system developed for the study includes 48 classifications and emphasizes critical facilities, especially lifelines, to establish a basis for future earthquake mitigation planning. These classifications are then combined with the estimates of physical damage to the structures and dependent lifelines (electrical, gas, water, etc.) as derived from the physical damage estimates by engineering classification, and with estimated occupancy rates, to estimate the number of deaths and injuries, as well as loss of function and restoration time for the facilities.

3) INVENTORY: In order to determine what type of damage can be expected by specific region within the study area, inventories of the structure types within those regions are used. In

general, the inventory for a seismic loss study requires data concerning the engineering and social classifications of structures as well as their location; the number of structures; the density of the population using the structure, and the replacement value. Detailed, comprehensive field surveys would have been extremely labor and cost intensive, and are not necessary for a study like this which focuses on an overall regional problem rather than on specific buildings. Consequently, the Loss Study relies heavily on existing data bases and available inventories from federal, state and local government agencies, augmented by information obtained from questionnaires, land use maps, aerial photographs, and expert opinion.

4) STRUCTURAL FRAGILITIES: Structural fragilities are used to estimate how much damage the different types of structures will suffer given the MMI shaking as postulated by the seismic hazard component. Using expert opinion and available earthquake damage data, fragilities for each class of structure can be estimated as a function of a damage factor (ratio of dollar loss to replacement value of the structure) and the MMI intensity shaking. The structural fragilities used in the Loss Study are called Damage Probability Matrices (DPMs). DPMs give the probabilities, for each expected MMI value and type of structure considered, that different amounts of damage will occur. This is a way to quantitatively account for the fact that two nearly identical buildings subjected to the same amount of shaking may not suffer identical amounts of damage. For example, 70% of buildings of a given type might have a predominant level of expected damage, but some might have a bit more and some a bit less damage than the predominant level.

5) EARTHQUAKE LOSS MODEL: With the other four components identified, calculated and assembled, the Loss Study then combines them in a loss model (equation) to produce the final damage, loss of functionality and casualty/death estimates for the study area. To account for fluctuating population density in different types of buildings at different times of the day, the model also factors in time of day to produce three (3) different casualty/death estimates, for 2:00 a.m.; 2:00 p.m.; and 4:30 p.m., respectively. To make its loss estimates more useful for earthquake response planning, the Loss Study divides the study area into nine (9) separate cells (as shown on Attachment 4), and implements the loss model using the components specific to each cell in order to generate damage, loss of functionality and casualty/death estimates specific to each cell.

Methodology Summary: In short, the model:

1) Postulates the seismic event (a 6.25 Richter magnitude earthquake with epicenter off Cape Ann, MA) recommended by the Seismic Risk Analysis Subcommittee;

2) Uses an updated formula provided by members of the Seismic Risk Analysis Subcommittee to determine expected MMI intensity ground shaking from that seismic event for different soil conditions (higher intensity for softer soils; lower intensity for stiffer soils);

3) Uses the soils maps prepared by Haley & Aldrich to identify the amount of MMI shaking expected per cell in the study area from the seismic event;

4) Categorizes the built environment of the study area into 24 different engineering classifications and, using the structur-

al fragilities data, estimates the amount of structural damage to each type of classification;

5) Further categorizes the built environment of the study area into 48 social function classifications and, using the structural fragilities data, estimates the loss of functionality of each classification;

6) Uses inventories compiled from several sources to estimate by study area cell:

a) the number and type of utilities, buildings and other structures in each of the 24 engineering and 48 social function classifications; and

b) the amount of expected damage and loss of functionality to those utilities, buildings and other structures given the MMI intensities expected for that cell;

7) Uses those estimates of damage and loss of functionality in each cell to estimate the number of earthquake-related deaths and casualties in each cell by factoring those damage estimates into an equation which relates damage and loss of functionality to casualties and deaths;

8) Further factors into that death/casualty equation three different times of day with three different facility occupancy rate estimates, resulting in three different death/casualty estimates for each cell.

IV. Loss Study Damage Estimates

The Loss Study summarizes the estimated structural damage from the postulated earthquake in three ways: in dollars for damage to buildings; in breaks per mile for pipelines; and in percentage of total functionality for both buildings and pipelines 72 hours after the earthquake. As previously stated, the study area is divided into nine (9) cells, as set forth in Attachment 4. Damage estimates for these cells are broken down into ten (10) separate classifications of facilities, as shown in the tables on Attachments 5-A through 5-K. The damage estimates for each of these types of facilities are as follows:

MEDICAL FACILITIES -- Hospitals, Nursing Homes, Ambulance Services, Medical Supply Houses, Blood Banks, Clinical Labs and Health Manpower (Workers/Professionals): The table on Attachment 5-A gives a summary of the damage and the 72-hour post-earthquake functionality for each of these types of facilities. Total damage to medical facilities is estimated at $96,495,000. Of more importance from a response planning perspective is the range of 72-hour postearthquake functionality of the medical facilities, which varies from a low of 14% to a high of 26%.[4] For ambulance services the 72-hour functionality is estimated at 18%.[5] This translates into a net loss in medical response capability of over 75% at a time when demand for medical response

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[4] Note: Although it is Massachusetts law that all hospitals and most nursing homes have backup power, the functionality evaluations of the Loss Study do not consider this because of the high seismic vulnerability of these types of equipment and the consequent potential for losing backup power. If backup power is available, the functionality of those facilities would increase slightly.

[5] Note: This is based on damage to the garages, and presumably more than 18% of the ambulances would be available for emergency response.

will be extremely high (see V. Loss Study Death and Casualty Estimates, below). The Study very appropriately recommends consideration of site-specific seismic risk studies for major medical facilities.

TRANSPORTATION FACILITIES AND SYSTEMS -- Highway Systems, Airport Facilities, Water Port Facilities and Public Transportation Systems: The table on Attachment 5-B gives the estimated damage and 72-hour postearthquake functionality for both the main and the distribution components of each of the transportation systems. Total damage to these facilities and systems is estimated at $70,821,000. Of particular importance are the Loss Study's estimates of 62% functionality of the airport facilities and 47% functionality of the water port facilities -- both are expected to be usable in a postearthquake response effort, although at significantly reduced operating levels. However, the Study does not closely consider soil liquefaction potential for Logan Airport (which is situated on low-lying filled land and extremely susceptible to soil liquefaction), and suggests making "(s)ite-specific evaluations of the soil conditions at runways and taxiways . . . to verify" the Study's airport functionality conclusion. The Committee notes that it is unclear whether URS adequately considered the present condition of Massachusetts bridges when it made its analysis of the transportation network for the Loss Study and therefore road transportation functionality might be overstated in the URS Loss Study.

GAS AND PETROLEUM FUEL FACILITIES: The table on Attachment 5-C shows the 72-hour postearthquake functionality for natural gas distribution components is high, ranging from 84% to 95%. Total damage to the natural gas system is estimated at $3,946,000. However, the 72-hour postearthquake functionality of the petroleum facilities is a low 47% because, as the Loss Study

points out, "(a) very inexpensive pipe break at a storage tank connection can render the storage tank useless 72 hours after the earthquake." The Study also notes that "(a) failure of this nature could pose a significant environmental hazard when the postulated earthquake occurs."

WATER AND SEWER UTILITIES: See the table on Attachment 5-D. The estimate of the 72-hour postearthquake functionality for the water system main components (aqueducts, tunnels, reservoirs and treatment plants) is 81%; for the distribution components (storage facilities, pressure control facilities and distribution pipelines) the estimates vary between 81 - 98%. Total damages for the water system are estimated at $2,298,000. A total of 29 pipe breaks were estimated by this evaluation. The study notes that no pipe breaks are reported for the main water components because aqueducts and tunnels are regarded as main water conduits by this study, and "treated as discrete (but long) facilities." It is upon the basis of this evaluation that the study concludes "water service to the study area is not expected to be severely impaired by the postulated earthquake." However, because of this methodological assumption, the Loss Analysis Committee is concerned that URS has not fully explored the possibility of an aqueduct failure for this Loss Study. Given the very real potential for such a failure and the serious fire fighting implications of such a failure, the Committee feels this issue should be examined as part of a broader study of the conflagration potential for the study area (see VII. Policy Implications and Committee Recommendations).

For the sewer system's main components (outfalls, treatment plants and tunnels), the 72-hour postearthquake functionality is 65%. For the distribution components (headworks, pumping stations and interceptor/collector lines), the 72-hour post-

earthquake functionality ranges from 72% to 89%, with total damages estimated at $6,658,000. Although 48 breaks are estimated for the 220 miles of distribution pipe in the study area, the Study concludes that "the sewer system will be adequately functional to serve the inhabitants of the study area following the postulated earthquake, and no major health hazard is expected." The Committee notes, however, that the loss of 35% of the sanitary sewer system may well lead to a significant dislocation of residents and businesses. This dislocation of residents may increase the number of persons requiring temporary housing, beyond those who URS estimates will need such housing due to the earthquake-related structural damage to their homes.

ELECTRIC POWER UTILITY: See the table on Attachment 5-E. The 72-hour postearthquake functionality damage factor for the main components (generating stations, major substations and major transmission lines) is 74%, while the estimates for the distribution components (distribution substations) are from 76 - 84%, with total damages to the system estimated at $57,724,000. Because of these relatively high functionality estimates, the Study concludes "electrical power will be available to serve the majority of the facilities in the study area following the postulated earthquake."

COMMUNICATIONS NETWORK -- Telephone, Radio and Television: See the table on Attachment 5-F. The telephone system is expected to lose 26% of its operating capacity 72 hours after the postulated earthquake, with total damages to the system estimated at $6,903,000. The Committee notes that this estimate poses a potentially significant emergency management problem because although the Study indicates 74% capacity for the telecommunications system, in the post-earthquake environment there will

likely be a need in excess of 100% system capacity. The result may be that a significant number of emergency calls over commercial telephone lines may not be handled expeditiously.

The television and radio systems are expected to have only 35% of their broadcast capability 72 hours after the earthquake, at a total damage cost of $7,589,000. As with medical facilities, although nearly all of the major radio stations in the area have emergency backup power, this was not factored in because of the seismic vulnerability of the equipment. If the backup power is functional after the earthquake, the Study indicates functionality would increase to 45% "because of the high dependence of radio and television on electrical power." The Committee notes that several of the major Boston area television towers are located just outside of the study area and are not listed in these figures. These would likely suffer similar damage, resulting in even less operability of this vital communication system.

EMERGENCY PUBLIC FACILITIES -- Police Stations, Fire Stations, Civil Defense Emergency Operating Centers, National Guard Armories: See the table on Attachment 5-G. The Loss Study estimates a dramatic decrease in postearthquake functionality for these emergency facilities, with 72-hour postearthquake functionality estimates between 16% - 26%. This translates to an average loss in response capability of over 75%. As the Loss Study states, given these projected losses in response capability, "the disaster response effectiveness of the existing emergency public facilities is questionable." Total damages are estimated at $9,737,000. The Committee believes this matter deserves the highest attention within the emergency management community, as these estimates have extremely negative implications for postearthquake fire fighting and emergency response.

RESIDENTIAL BUILDINGS: See the table on Attachment 5-H. The 72-hour functionality for residential buildings ranges from a low of 57% to a high of 62% for the nine (9) different study area cells. This relatively high degree of functionality is the result of two factors: 1.) the low damage factors to wood frame housing, which comprises the majority of the housing stock in the study area; and 2.) the low dependence of residential building functionality on lifelines. Total damage is estimated at $2,506,282,000, with an estimated 25,600 persons displaced or homeless 72 hours after the earthquake. The Committee notes that these estimates do not include persons displaced by fire following the earthquake. Since the Loss Study indicates that the potential for a conflagration in the study area is significant (see discussion of conflagration, below), the total number of persons displaced could be significantly higher.

SCHOOLS -- Public K-12, Private K-12, Colleges and Universities: See the table on Attachment 5-I. The 72-hour postearthquake functionality for schools, colleges and universities vary from a low of 11% to a high of 19%. This dramatic reduction in functionality (from 81% to 89%) is a function of the high dependence of schools on lifelines for full functionality.[6] Consequently, although most schools, colleges and universities will not be in condition to serve as places of education within 72 hours of the earthquake, the Study indicates many of their buildings may be usable, or could be made usable, as emergency shelters. Total damage to schools, colleges and universities is estimated at $991,685,000.

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[6]Note: Because the majority of the schools in the study area are old, and are frequently constructed of masonry materials, the Loss Study concludes that some of these buildings will be severely damaged during the postulated earthquake.

SPECIAL FACILITIES -- Dams and Tall Buildings: See the table on Attachment 5-J. URS estimates very low damage for dams in the study area, with approximately 70% functionality 72 hours after the earthquake. The Study estimates only $95,000 in damages for dams in the study area, and concludes that no dam failures are expected. However, the Committee notes that URS does not clearly explain in the Study why the several high hazard and/or structurally unsafe dams documented within the study area would not fail during the postulated earthquake.

Conversely, 72-hour postearthquake functionality for tall buildings[7] is estimated at only 27%. This high loss of functionality is due to the high damage expected from the high MMI/severe ground motion expected to be experienced in cell 7, (large portions of Boston, Cambridge and Winthrop, see Attachment 4) where most of these buildings are located. Although functional disruption and moderate structural damage are expected for these buildings, no collapses are expected. Damages of $389,764,000 are expected for tall buildings in the area.

SUMMARY OF DAMAGE AND 72-HOUR FUNCTIONALITY: See the table on Attachment 5-K for summary of all estimates of direct earthquake-related damages. Because of inherent uncertainties about the precise accuracy of the figures in Attachment 5-K, the Study indicates that the best estimate is that the total cost of structural damages to the built environment from the postulated earthquake will be approximately **5-6 billion dollars**, with a possible range of **2-10 billion dollars**.

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[7]A tall building is defined in this study as a building with either 20 or more stories or a height of over 325 feet. A total of 38 tall buildings were identified in the study area, almost all of which are located within cell 7.

The Committee notes that the Study estimates make no attempt to estimate the additional costs due to damage from a fire or urban conflagration following the earthquake. The Study does state that "(i)n Metropolitan Boston . . . the threat of conflagration has to be taken seriously, at least in some of the cells" and goes on to enumerate four (4) specific factors contributing to the conflagration potential:

1) Significant portions of the study area are comprised of poor soils. The Study estimates several pipe breaks in water, gas and oil pipes in these areas. The consequences of pipe breaks, and potential breaks in electric lines, is to produce possible ignitions and fires.

2) Some of these areas, such as cells 5 and 7, have a concentration of old buildings, which are expected to suffer significant damage and add fuel to the fires.

3) Most of the fire stations in the study area are constructed of unreinforced brick masonry, which is the most hazardous class of buildings in an earthquake. Earthquake damage to these fire stations may damage, or block access to, fire fighting equipment and personnel.

4) The Study shows damage to highways is also greatest in these areas of poor soils.

The Committee attempted to develop reasonable estimates of the damages not included in the URS estimates of damage from an earthquake in metropolitan Boston. The principal damages not included in the URS study would be due to conflagration or earthquake induced fires, soil liquefaction, economic costs of

business interruption and lost wages due to business interruption.

Precise estimates of these damages would require a detailed study. However, several experts in the field of disaster cost estimation were interviewed as part of the preparation of this report. (See, Acknowledgements in Section IX for the names and affiliation of the experts). It was the consensus of these experts: (a) that in a situation, like that in Metropolitan Boston, where there appeared to be a substantial risk of conflagration, it would be reasonable to estimate the costs of fire following an earthquake to be approximately fifty to one hundred percent of the damage due to earth movement; (b) that a reasonable approximation of the economic costs of business interruption would be two to three hundred percent of the damages due to earth movement; and (c) that the cost of lost wages would be significant, but not likely in the billions of dollars.

Finally, the Committee notes that the Loss Study damage estimates account only for damages within the study area (essentially those communities encompassed by State Route 128). An earthquake with the same strength and location as that postulated for the Loss Study would result in additional damage outside this study area, particularly Northern Massachusetts and Southern New Hampshire.

The damage estimates of the URS Study should be read with these omitted factors in mind.

V. Loss Study Death and Casualty Estimates

The Loss Study summarizes the estimated casualties due to ground shaking from the postulated earthquake within the study area for

each of the nine (9) cells in the study area and for three times of the day: 2:00 a.m., 2:00 p.m. and 4:30 p.m. The casualties are then estimated by three categories: deaths, major injuries requiring hospitalization and minor injuries not requiring hospitalization. The individual totals for these categories, by cell and time of day, are shown on Attachment 6. It should be noted that there is a potential for additional loss of life and injury due to factors not included in the study, such as fire following the earthquake and soil liquefaction. Additional loss of life and injury is possible outside the study area as well.

The loss model factors in time of day to account for fluctuations in the occupancy of different elements within the built environment during the course of a day. It also accounts for increased population within the study area due to commuting workers. These fluctuating occupancy rates are combined with the estimated structural fragilities assigned to the different engineering classifications of the built environment in the study area to produce the three (3) sets of casualty figures. Consequently, the highest casualty numbers (360 deaths, 1,414 serious injuries, 10,496 minor injuries) are for a 2:00 p.m. earthquake because of the high damage expected for the engineering classifications which constitute the primary types of construction for schools, businesses and factories (masonry, tilt-up, etc.). These structures are expected to perform poorly during a seismic event in comparison to those in the engineering classification (wood-frame houses) which comprises the bulk of the residences for the population in this study area. Based on this premise of higher casualties for times of day when occupancy or use of structures with the highest structural fragilities is greatest, the study results conclude that the population of the study area will be at greatest risk while at their places of work or education (2:00 p.m.); safer (assuming the transportation system performs as well

as the URS Study indicates it will) commuting between their places of work or education and their residences (4:30 p.m.) ; and safest when presumably asleep in their residences (2:00 a.m.).

The Loss Study also includes separate figures for casualties in schools for a 2:00 p.m. event, as shown in Attachment 7. These separate figures are provided to emphasize the point made in the Study that, because of the age and unreinforced masonry construction of many of the schools in the study area, "(t)he poor performance of the schools raises questions about the safety of the school children if the earthquake were to occur during school hours."

VI. Loss Estimation Methodology Review and Limitations

It is the conclusion of the Loss Analysis Committee that the estimates of damage, loss of functionality and casualties/deaths contained in the Loss Study constitute a sufficient basis for developing an earthquake response plan for New England. The Loss Analysis Committee is aware that the resolution of the contractual difficulties between MCDA and URS may not require URS to make any further revision of this Loss Study. Nonetheless, there are several short-comings in the textual explanation of facets of the methodologies employed, as well as omissions of several potential sources of earthquake losses, as identified below, which committee members feel should be pointed out and be resolved, if possible, through further research and analysis. However, these short-comings should not be permitted to impede expeditious progress towards preparing for and mitigating the consequences of a major earthquake in Massachusetts and elsewhere in New England. Major ares requiring further research are:

1) INVENTORY OMISSIONS: There are many obvious shortcomings in the inventory prepared by URS. For example, in one table the population for every 4-year university/college in the study area is listed as "0." A review of the study indicates that it is likely that some number was assigned to student populations in computing likely death and injuries, however the numbers used cannot be checked without additional analysis. While some of this was expected, a more complete explanation of the individual inventories and the information contained therein would be useful for those who wish to use these inventories as a starting point for future studies.

2) SOIL LIQUEFACTION: While the Loss Study could not go into the details as to where soil liquefaction could occur, URS does not make adequate mention of this important phenomenon in the Study. More investigation of how damage and functionality estimates might change should soil liquefaction occur under parts of the study area is essential. Such an analysis might well modify damage estimates substantially upward in areas such as Boston's waterfront, Back Bay and Beacon Hill. When soil liquefaction is factored into damage estimates, the functionality of port facilities, Logan Airport and the infrastructure throughout the study area might well be shown to be less than that currently estimated. Lessening the functionality of such critical facilities would substantially influence emergency preparedness planning for the emergency use of Logan Airport and the Boston Harbor facilities in particular.

3) DAMAGE TO MMI = V AREAS: URS makes the assumption in the Loss Study that there will be no damage in areas of MMI = V shaking. URS should have explained or justified this assumption in the Loss Study. Further research into this issue would be worthwhile.

4) CONFLAGRATION POTENTIAL: As previously discussed, although the Loss Study does discuss the potential of earthquake-induced catastrophic fire for the study area, with pointed reference to the conflagration potential of San Francisco and the similarities between that city and the Study Area, none of the Study estimates -- damage, functionality or casualties/deaths -- factors in a conflagration element. More investigation of how those estimates might change should some conflagration occur in parts of the study area should be conducted.

5) USE OF EXPERT OPINION: Although the Loss Study does discuss the methodologies used in it, such details as exactly how expert opinion was applied; the nature of the involvement of their consulting panel of experts; exactly what damage transfer functions between California and the study area were used; and the range of uncertainties for the estimates it provides do not have complete explanations. Such explanations should be included for this report to fully meet generally acceptable professional standards.

Despite these short-comings, the Loss Analysis Committee believes that the estimates for earthquake losses in the study area provide a sufficient basis for planning, earthquake preparedness and response activities in New England.

VII. Policy Implications and Committee Recommendations

In view of the above findings of the Loss Analysis Committee, it is the consensus of this Committee that the investigation into the vulnerability of the Boston Metropolitan Area prepared by URS Consultants, Inc./John Blume & Associates, Engineers cannot be

considered a final publishable report. However, the loss estimates contained in the URS study, as clarified by this Committee's report, are sufficient to be used as a basis for earthquake response planning at the federal, state and local level, and as an impetus for a program of greater earthquake hazard awareness and preparedness in New England. The Committee therefore recommends to the Director of the MCDA that this Summary Report be used as a vehicle for the public release of the Loss Study estimates.

The committee offers the following recommendations:

1) **Dissemination of the Information in this Report:**

A) MCDA should immediately disseminate this Summary Report to:

i) The Chief Executives and Emergency Management Directors of each of the 31 municipalities in the study area, at the soonest possible time;

ii) The Massachusetts State Board of Building Regulations and Standards as well as to the Board's Seismic Advisory Committee for their use in determining its implications for modifications of the State Building Code;

iii) The hospital associations and the administrators of the hospitals inventoried in the Study, particularly those involved in the National Disaster Medical System;

iv) The Fire Chiefs Association, the Fire Academy and the Fire Chiefs of each of the 31 municipalities in the study area;

v) All State, local, public and semi-public agencies, schools and utilities affected by this Study;

vi) The State Emergency Management Agency Directors of the other five (5) New England States for their use in their state earthquake response planning and public awareness efforts.

B.) Given that the results of this Study are to some degree applicable throughout New England, as well as the entire east coast, it must be emphasized that although the costs in lives and dollars from a New England earthquake would most likely be greatest in the study area, similar but proportionately less damages could be caused elsewhere in New England. Consequently, the Committee recommends that FEMA, in cooperation with the New England Seismic Advisory Committee (NESAC) of the New England Governors' Conference, coordinate the general release of the Summary Report through a program of dissemination which includes sending copies to the following:

i) The various architectural and engineering associations, such as the American Institute of Architects, Boston Society of Architects, American Society of Civil Engineers, Boston Society of Civil Engineers, National Society of Professional Engineers, Associated General Contractors and the Earthquake Engineering Research Institute;

ii) The various insurance industry associations (AIA, AAI, III, etc.);

iii.) The New England utility companies especially New England Telephone, the various companies involved in distributing natural gas and petroleum products, and their regional associations;

iv) Industry and building owner associations such as Associated Industries of Massachusetts;

v) Specific volunteer disaster relief organizations including: The American Red Cross, Salvation Army, Seventh Day Adventists, American Radio Relay League and Civil Air Patrol;

vi) The Earthquake Engineering Research Institute; and the various regional seismic safety organizations.

2) Additional Research:

A) Specific research into better defining and understanding the seismic hazard of the Boston Area should be continued. In particular, this research should seek to clarify where strong earthquakes may be centered in or near the Boston area, how strong those earthquakes might be and what are the chances of future damaging earthquakes . Funding for regional earthquake monitoring in New England, slated to be terminated by the U.S. Nuclear Regulatory Commission in 1992, should be continued past that date as an integral part of this research effort and as an important information resource for emergency/disaster planning efforts.

B) A study of the conflagration potential for the study area should be performed. Such a study should be patterned after the one made for the Los Angeles and San Francisco areas by

the All-Industry Research Advisory Council (AIRAC)[8], or other studies sponsored by federal agencies such as the National Science Foundation.

C) A study of the indirect consequences of the postulated earthquake (i.e., in terms of economic interruption) should be performed. Again, such a study should be patterned after the one made for the Los Angeles area by the All-Industry Research Advisory Council (AIRAC)[9].

D) A study of liquefaction potential in the study area in general should be performed. Such a study should include site-specific studies of the liquefaction potential for Logan Airport, the rail transportation systems and Boston's port facilities, as well as the subway and road portions of the transportation network, particularly those portions of the network which are below ground.

E) Site-specific seismic vulnerability studies of emergency public facilities and major medical facilities should be done.

F) Site-specific seismic vulnerability studies of dams, particularly those already documented as structurally unsafe and/or high hazard dams should be done.

G) Site-specific research should be done to determine how to

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[8] All-Industry Research Advisory Council, Fire Following Earthquake: Estimates of the Conflagration Risk to Insured Properties in Greater Los Angeles and San Francisco, March 1987.

[9] All-Industry Research Advisory Council, Earthquake Losses Under Workers Compensation and General Liability, October 1988.

mitigate or avoid the environmental consequences of a major earthquake-induced release of hazardous materials.

3) Resume Massachusetts Participation in Federal Earthquake Program: MCDA should continue its present efforts to pursue funding through the budgetary process to enable Massachusetts to resume its full participation in the federal Earthquake Preparedness Program, which encompasses public awareness, mitigation and preparedness.

In conclusion the Committee notes with concern that studies of damage resulting from several destructive earthquakes in recent years (e.g., 1976 Tangshan, China; 1985 Mexico City; 1988 Spitak, Armenia) have clearly demonstrated that the following factors contribute most heavily to earthquake loss: building construction, soil conditions, lifelines (transportation, communications, water, sewage), time of day/season and short-term emergency response (preparedness). In particular, the Tangshan and Spitak earthquakes (magnitude 7.8; more than 240,000 fatalities; and magnitude 6.8; more than 25,000 fatalities, respectively) occurred in areas that are not tectonic plate boundaries like Mexico or California, and in which, as in New England, people were not sufficiently prepared for a damaging earthquake due to their low frequency of occurrence. We believe that the publication and implementation of this committee's report and recommendations is a suitable beginning of New England's efforts to support the United States efforts to plan for and mitigate results of natural hazards during this International Decade For Natural Disaster Reduction.

VIII. Acknowledgements

The Members of the Loss Analysis Committee would like to thank several members of the staff of the Federal Emergency Management Agency for their assistance in the preparation and review of this report: Mr. Daniel Catlett (writer), Mr. Richard Strome (reviewer), Mr. Kenneth Horak (reviewer), Mr. Ugo Morelli (reviewer), Mr. Edward Thomas (writer/editor), Mr. Michael Goetz (editor), Ms. Ann Donoghue (proofreader), Ms. Mary Kennedy (proofreader), Ms. Elizabeth Rosario (typist), Ms. Susan Healy (typist) and Ms. Mary Fallon (typist). In addition the Committee would like to acknowledge the significant input concerning the dollar costs of Earthquake related damages provided to this report by: Eugene Lecompte, President National Committee on Property Insurance, Boston, Massachusetts; John Drennan, Vice President, Allstate Insurance Company, Northbrook, Ill; and Karen M. Clark, President, Applied Insurance Research, Boston, Massachusetts. Mr. LeCompte also made valuable suggestions for changes in the report.

IX. Committee Member Biographies

1) **Dr. John Ebel** has a Ph.D in geophysics from the California Institute of Technology (1981) and a B.S. in Physics from Harvard University (1975). Since 1981 Dr. Ebel has been the Assistant Director of the Weston Observatory of Boston College and is an Associate Professor of Geophysics at Boston College. He is the Principal Investigator of the 29-station New England Seismic Network, operated by Weston Observatory.

2) **Mr. Edward Fratto** has a Master of Urban Affairs Degree from Boston University with a concentration in public policy analysis and urban hazard management. Since 1981 Mr. Fratto has been with

the Massachusetts Civil Defence Agency and Office of Emergency Preparedness, responsible for the development of emergency plans, programs and policy. Among many professional affiliations and activities, Mr. Fratto has testified before Congress on earthquake preparedness and served as a member of the National Academy of Science, National Research Council on Earthquake Loss Estimation Methodology.

3) **Dr. Katharine Kadinsky-Cade** has a Ph.D. in Geophysics (1985) and a B.A. in Physics (1978), both from Cornell University. She has been conducting basic research on earthquake source processes, seismicity, tectonics and seismic wave propagation since that time. Her involvement with this study dates back to 1986-1987, when she operated M.I.T.'s network of regional seismic stations (Massachusetts, New Hampshire) as part of the Northeastern U.S. Seismic Network's effort to monitor earthquake activity in New England.

4) **Mr. Norton Remmer** is principal of Norton S. Remmer, P.E., Consulting Engineers of Worcester, MA. He is chairman of the Massachusetts Seismic Advisory Committee and has been involved in the development of national seismic studies and documents, including ATC-3 and the National Earthquake Hazard Reduction Program (NEHRP) Seismic Provisions. He is a Registered Professional Engineer in civil, structural and mechanical engineering and a graduate of Worcester Polytechnic Institute, Yale University and Oxford University, England.

5.) **Edward Thomas, Esq.**, is the Director of the Disaster Assistance Programs Division of FEMA Region I. He was employed by the U.S. Department of Housing and Urban Development from 1969 to 1979 in programs of environmental review, natural hazard mitigation and housing construction. Since 1979 he has worked

for the U. S. Federal Emergency Management Agency managing programs of emergency preparedness planning and natural hazards reduction. A graduate of Fordham College and the New England School of Law, he has lectured and published numerous articles on natural hazards reduction, emergency planning and the legal aspects of land use regulation.

6.) Dr. M. Nafi Toksoz is Professor of Geophysics at the Massachusetts Institute of Technology and Director of the Wallace Geophysical Observatory and the Earth Resources Laboratory. He has studied damaging earthquakes all over the world. He has served on a number of national and international committees dealing with seismic hazards, including the National Research Council Panel on Earthquake Prediction and the National Earthquake Hazard Reduction Program. He is currently a member of the NRC Panel on Real-Time Earthquake Warning. He received his engineering degree from the Colorado School of Mines and his M.S. and Ph.D. degrees from the California Institute of Technology. He has been a faculty member at M.I.T. since 1965.

7.) Mr. Kenneth Wiesner, P.E., is a Senior Associate with LeMessurier Consultants, Inc. in Cambridge, MA. He received B.S. and M.S. degrees in Civil Engineering from Northwestern University and M.I.T, respectively. With over 30 years of experience in the structural engineering of buildings, Mr. Wiesner serves as Secretary of the Seismic Advisory Committee to the Massachusetts State Building Code.

Attachment 1

CITIES INCLUDED IN THE METROPOLITAN

BOSTON EARTHQUAKE LOSS STUDY

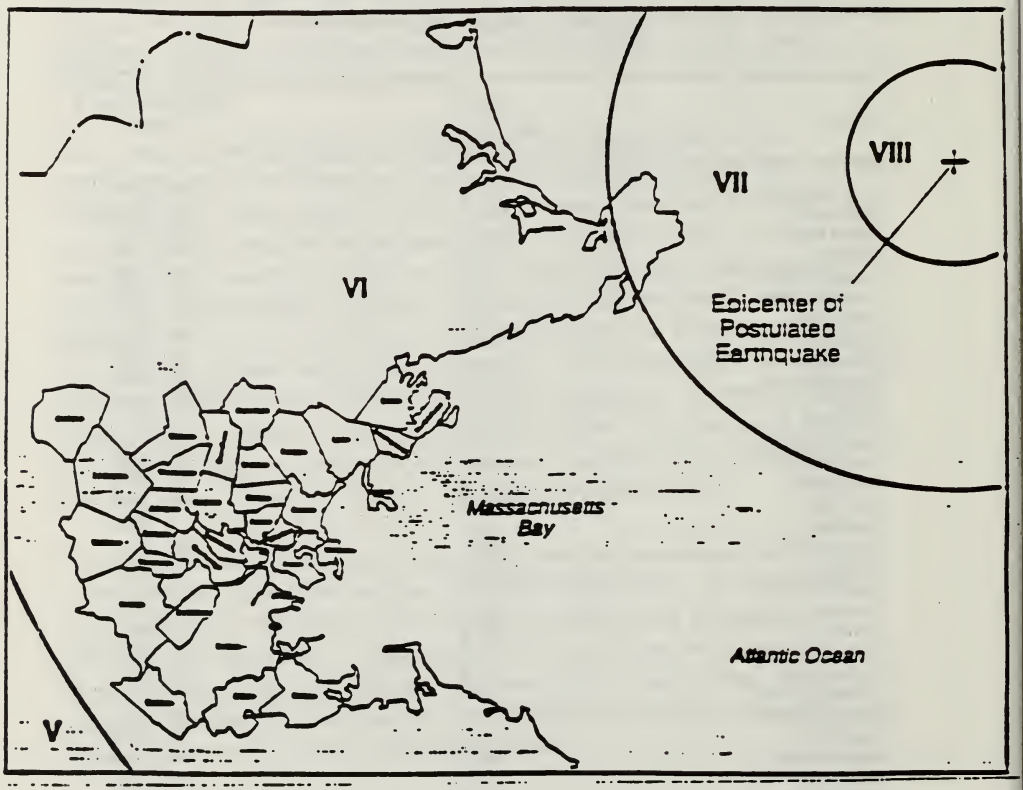
City	Area (sq miles)	Population * (1986)
Arlington	5.2	44,350
Bedford	13.7	12,490
Belmont	4.6	25,020
Boston	43.7	573,600
Brookline	6.6	52,360
Cambridge	6.3	91,260
Chelsea	1.9	25,640
Dedham	10.5	23,810
Everett	3.4	36,330
Lexington	16.5	28,610
Lynn	10.5	78,560
Malden	5.1	53,490
Marblehead	4.4	19,580
Medford	8.2	56,830
Melrose	4.7	28,790
Milton	13.1	25,500
Nahant	1.0	3,940
Newton	17.9	82,140
Quincy	16.5	82,630
Revere	6.0	43,510
Salem	8.0	38,050
Saugus	10.6	25,860
Somerville	3.9	72,280
Stoneham	6.0	22,550
Swampscott	3.1	13,330
Wakefield	7.4	25,170
Waltham	12.4	57,090
Watertown	4.1	32,890
Winchester	5.9	20,120
Winthrop	1.6	18,640
Woburn	12.9	37,380
TOTAL	275.7	1,751,800

* Source: Massachusetts Department of Revenue

Attachment 1-A

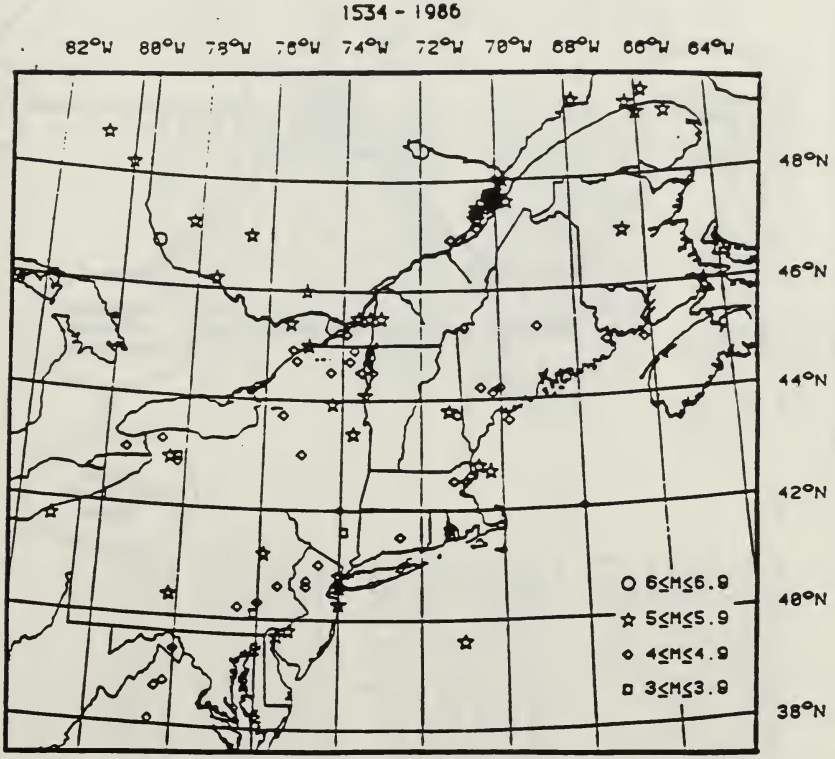
LOCATION OF EPICENTER OF POSTULATED EARTHQUAKE

(Numerals [V - VIII] Indicate Average Mercalli Intensity)



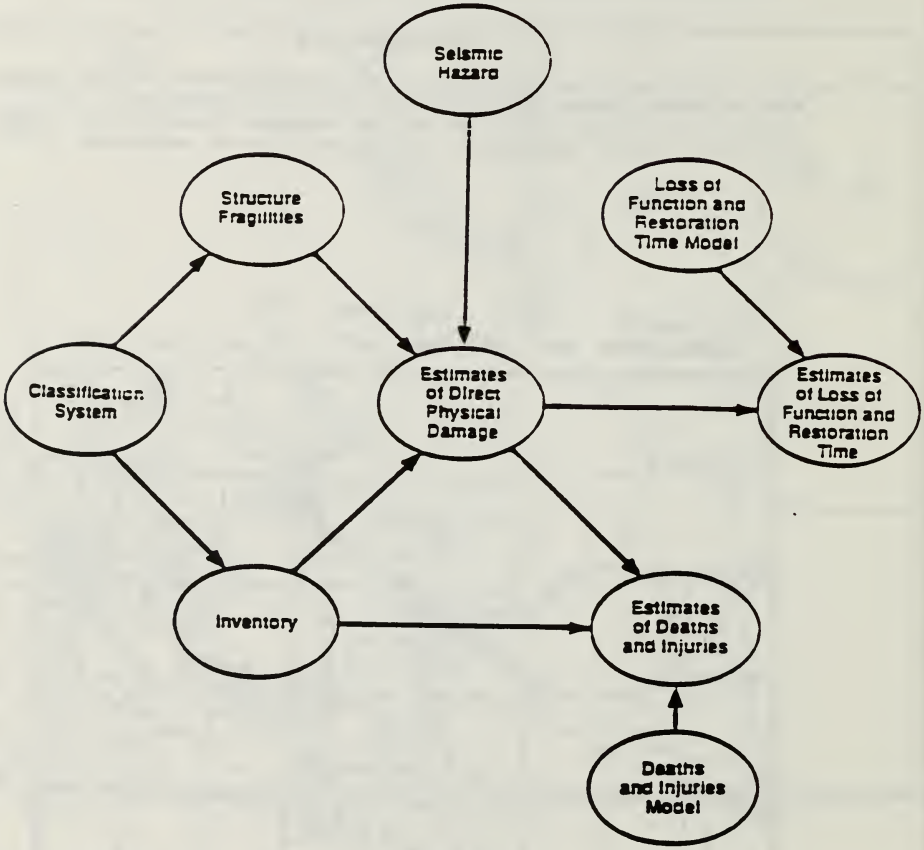
Attachment 1-B

Map of all known earthquakes for the northeastern United States and adjacent Canada with Modified Mercalli intensity VI or greater or Richter magnitude 5.0 or greater through June, 1986, plotted by their measured or estimated Richter magnitude.



Attachment 2

FLOWCHART OF EARTHQUAKE LOSS ESTIMATION METHODOLOGY


Seismic Hazard
Structure Fragilities
Loss of Function and Restoration Time Model
Classification System
Estimates of Direct Physical Damage
Estimates of Loss of Function and Restoration Time
Inventory
Estimates of Deaths and Injuries
Deaths and Injuries Model

Attachment 3

ABRIDGED MODIFIED MERCALLI INTENSITY SCALE

I. Not felt except by a very few under especially favorable circumstances. (I Rossi-Forel Scale.)

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (I Rossi-Forel Scale.)

III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated. (III Rossi-Forel Scale.)

IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed, walls make creaking sound. Sensation like heavy truck shaking building. Standing motorcars rocked noticeably. (IV to V Rossi-Forel Scale.)

V. Felt by nearly everyone, many awakened. Some dishes, windows, and so on broken; cracked plaster in a few places; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI Rossi-Forel Scale.)

VI. Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster and damaged chimneys. Damage slight. (VI to VII Rossi-Forel Scale.)

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving cars. (VIII Rossi-Forel Scale.)

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving cars disturbed. (VIII to IX Rossi-Forel Scale.)

IX. Damage considerable in specially designed structures; well designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (IX+ Rossi-Forel Scale.)

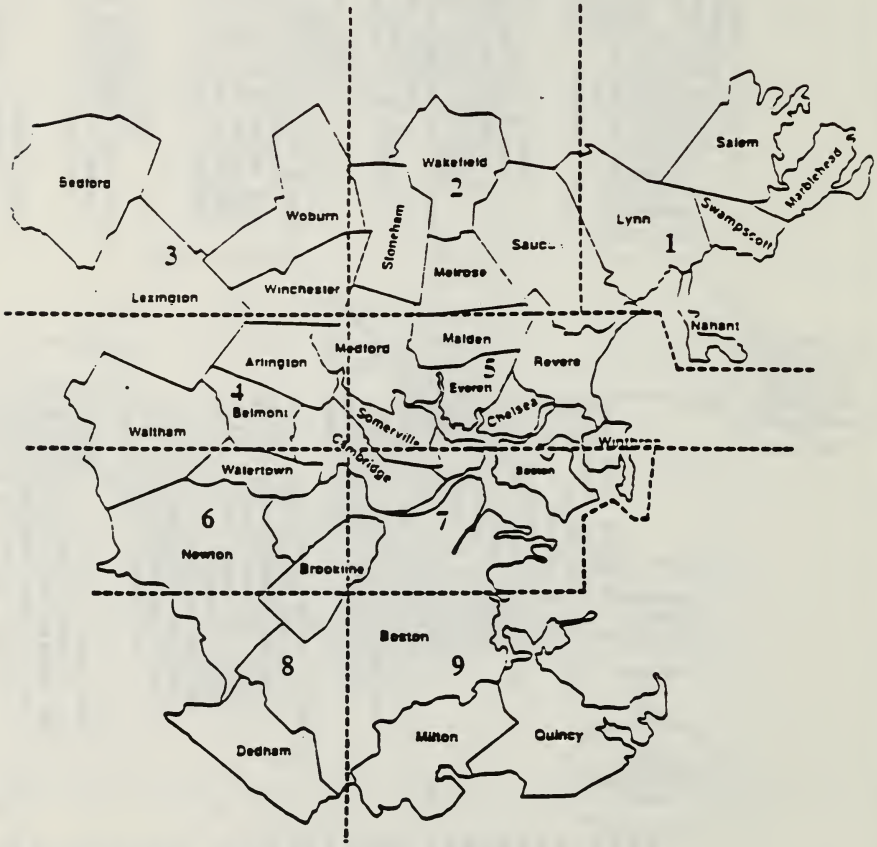
X. Some well built woodsn structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks, and steep slopes. Shifted sand and mud. Water splashed, slopped over banks. (X Rossi-Forel Scale.)

XI. Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into the air.

Attachment 4

MAP OF STUDY AREA SHOWING THE 31 CITIES AND 9 CELLS



Attachment 5-A

MEDICAL FACILITIES

DAMAGE AND 72-HOUR POSTEARTHQUAKE FUNCTIONALITY

Facility	Cell	Damage ($ thousands)	*Damage Factor (D/RV)	Functionality (%)
Hospitals	1-3	3,042	0.021	24
Hospitals	4,6	8,614	0.052	16
Hospitals	5,7	52,279	0.151	16
Hospitals	8,9	4,939	0.036	14
Hospitals Total	1-9	68,874		
Clinical Labs	1-3	323	0.066	25
Clinical Labs	4,5	386	0.079	23
Clinical Labs	7	2,385	0.152	18
Clinical Labs	6,8,9	342	0.087	21
Clinical Labs Total	1-9	3,436		
Ambulance Services	1-9	591	0.127	18
Medical Supply Houses	1-9	583	0.108	14
Blood Banks	1-9	660	0.130	17
Nursing Homes	1	1,833	0.056	24
Nursing Homes	2,3	1,105	0.047	26
Nursing Homes	4	1,332	0.068	24
Nursing Homes	5	5,227	0.088	21

Attachment 5-A (Continued)

Facility	Cell	Damage ($ thousands)	*Damage Factor (D/RV)	Function-ality (%)
Nursing Homes	6	4,597	0.075	23
Nursing Homes	7	3,259	0.062	23
Nursing Homes	8	876	0.034	25
Nursing Homes	9	4,092	0.055	22
Nursing Homes Totals	1-9	22,321		
Medical Facilities Total	1-9	96,465		

*Damage Factor, as used in the tables on Attachments 5-A through 5-K, is defined as expected damage (D) divided by the replacement value (RV) of the structures involved.

Attachment 5-B

TRANSPORTATION FACILITIES AND SYSTEMS:

DAMAGE AND 72-HOUR POSTEARTHQUAKE FUNCTIONALITY

Facility	Cell	Damage ($ thousands)	Damage Factor (D/RV)	Functionality (%)
HIGHWAY SYSTEM				
Main Components	1-9	20,788	0.064	67
Distribution Components	1	--	--	--
Distribution Components	2	143	0.061	66
Distribution Components	3	119	0.035	61
Distribution Components	4	*	*	100
Distribution Components	5	454	0.066	61
Distribution Components	6	422	0.059	73
Distribution Components	7	394	0.066	61
Distribution Components	8	24	0.010	61
Distribution Components	9	143	0.038	61
Highway System Total	1-9	22,487		
AIRPORT FACILITIES				
Main Components	1-9	14,826	0.045	62
Distribution Components	1-9	7,246	0.037	62
Airport Facilities Total	1-9	22,072		
WATER PORT FACILITIES	1-9	16,124	0.052	47

Attachment 5-B (continued)

Facility	Cell	($ thousands)	Damage Factor (D/RV)	Functionality (%)
PUBLIC TRANSPORTATION				
Main Components	1-9	7,317	0.089	62
Distribution Components	1-5	802	0.054	65
Distribution Components	6-9	2,019	0.085	61
Public Transportation Total	1-9	10,138		
Transportation Facilities and Systems Total	1-9	70,821		

* Negligible amount

Attachment 5-C

GAS AND PETROLEUM FUEL UTILITIES:

DAMAGE AND 72-HOUR POSTEARTHQUAKE FUNCTIONALITY

Facility	Cell	Damage ($ thousands)	Damage Factor (D/RV)	Number of Breaks	Functionality (%)
NATURAL GAS					
Main Components	1-9	3,492	0.040	3	89
Distribution Components	1	45	0.041	4	84
Distribution Components	2	10	0.016	1	95
Distribution Components	3	11	0.019	4	95
Distribution Components	4	23	0.023	6	95
Distribution Components	5	140	0.079	6	84
Distribution Components	6	34	0.063	5	84
Distribution Components	7	54	0.039	5	95
Distribution Components	8	110	0.121	2	84
Distribution Components	9	26	0.020	4	95
Natural Gas Total	**1-9**	**3,945**		**40**	

Attachment 5-C (continued)

Facility	Cell	Damage ($ thousands)	Damage Factor (D/RV)	Number of Breaks	Functionality (%)
PETROLEUM FUEL	1-9	2,296	0.031	--	47
Repair Cost for Breaks		280			
Gas and Petroleum Fuel Utilities Total		6,521			

Attachment 5-D

WATER AND SEWERAGE UTILITIES:

DAMAGE AND 72-HOUR POSTEARTHQUAKE FUNCTIONALITY

Function-ality Facility	Cell	Damage ($ thousands)	Damage Factor (D/RV)	Number of Breaks	(%)
WATER SYSTEM					
Main Components	1-9	1,812	0.010	0	81
Distribution Components	1	33	0.007	3	83
Distribution Components	2	21	0.006	1	90
Distribution Components	3	328	0.024	5	83
Distribution Components	4	85	0.022	4	82
Distribution Components	5	5	0.027	5	81
Distribution Components	6	14	0.010	5	81
Distribution Components	7	*	*	3	86
Distribution Components	8	*	*	1	98
Distribution Components	9	*	*	2	98
Water System Total	1-9	2,289		29	
SEWERAGE SYSTEM					
Main Components	1-9	2,938	0.020	3	65

Attachment 5-D (continued)

Facility	Cell	Damage ($ thousands)	Damage Factor (D/RV)	Number of Breaks	Functionality (%)
Distribution Components	1	208	0.016	7	72
Distribution Components	2	10	0.002	1	82
Distribution Components	3	414	0.023	11	76
Distribution Components	4	83	0.024	2	76
Distribution Components	5	42	0.033	7	78
Distribution Components	6	--	--	3	89
Distribution Components	7	--	--	7	89
Distribution Components	8	--	--	2	89
Distribution Components	9	126		5	72
Sewerage Cost System Total	1-9	3,821		48	
Repair Cost for Breaks		539			
Water and Sewerage Utilities Total	1-9	6,658			

* Negligible amount

Attachment 5-E

ELECTRIC POWER UTILITIES:

DAMAGE AND 72-HOUR POSTEARTHQUAKE FUNCTIONALITIES

Facility	Cell	Damage ($ thousands)	Damage Factor (D/RV)	Functionality (%)
Main Components	1-9	56,386	0.050	74
Distribution Components	1-2	374	0.016	84
Distribution Components	3-4	240	0.024	81
Distribution Components	5-6	309	0.033	83
Distribution Components	7-9	415	0.042	76
Electric Power Utility Total	1-9	57,724		

Attachment 5-F

COMMUNICATIONS NETWORK:

DAMAGE AND POSTEARTHQUAKE FUNCTIONALITIES

Facility	Cell	Damage ($ thousands)	Damage Factor (D/RV)	Functionality (%)
Telephone	1-9	6,903	0.046	74
Radio and Television	1-9	7,589	0.090	35
Communications Network Total	1-9	14,492		

Attachment 5-G

EMERGENCY PUBLIC FACILITIES:

DAMAGE AND 72-HOUR POSTEARTHQUAKE FUNCTIONALITIES

Facility	Cell	Damage ($ thousands)	Damage Factor (D/RV)	Functionality (%)
Police Stations	1-3	863	0.070	26
Police Stations	4-6	1,794	0.118	21
Police Stations	7-9	1,217	0.107	17
Police Stations Total	1-9	3,874		
Fire Stations	1	778	0.086	23
Fire Stations	2,3	276	0.073	22
Fire Stations	4,6	722	0.074	22
Fire Stations	5	1,459	0.144	19
Fire Stations	7	1,339	0.123	19
Fire Stations	8	*	*	--
Fire Stations	9	199	0.033	16
Fire Stations Total	1-9	4,773		
National Guard Armories	1-9	859	0.142	18

Attachment 5-G (Continued)

Facility	Cell	Damage ($ thousands)	Damage Factor (D/RV)	Functionality (%)
Emergency Operating Centers	1,2,5	125	0.088	23
Emergency Operating Centers	3,4,6-9	106	0.074	20
Emergency Operating Centers Total	1-9	231		
Emergency Public Facilities Total	1-9	9,737		

* Negligible damage

Attachment 5-H

RESIDENTIAL BUILDINGS:

DAMAGE AND 72-HOUR POSTEARTHQUAKE FUNCTIONALITIES

Facility	Cell	Damage ($ thousands)	Damage Factor (D/RV)	Function-ality (%)	Homeless (persons)
Residences	1	218,653	0.037	60	1,340
Residences	2	99,027	0.023	62	480
Residences	3	149,390	0.033	58	400
Residences	4	187,965	0.030	58	1,360
Residences	5	420,332	0.068	57	5,540
Residences	6	242,930	0.054	59	2,750
Residences	7	624,175	0.100	59	7,780
Residences	8	161,841	0.033	62	1,600
Residences	9	401,969	0.034	59	4,350
Residential Buildings Total	1-9	2,506,282			25,600

Attachment 5-I

SCHOOL BUILDINGS:

DAMAGE AND 72-HOUR POSTEARTHQUAKE FUNCTIONALITY

Facility	Cell	Damage ($ thousands)	Damage Factor (D/RV)	Functionality (%)
Public K-12	1	12,542	0.080	14
Public K-12	2	6,816	0.063	16
Public K-12	3	6,541	0.078	13
Public K-12	4	11,862	0.081	13
Public K-12	5	37,975	0.136	11
Public K-12	6	12,112	0.086	13
Public K-12	7	27,078	0.130	13
Public K-12	8	862	0.009	19
Public K-12	9	17,979	0.069	13
Public K-12 Total	1-9	133,767		
Private K-12	1	2,818	0.108	14
Private K-12	2	898	0.061	16
Private K-12	3	134	0.017	16
Private K-12	4	6,675	0.116	13
Private K-12	5	11,544	0.155	11
Private K-12	6	3,710	0.079	13
Private K-12	7	10,668	0.137	13
Private K-12	8	316	0.007	19
Private K-12	9	7,383	0.071	13
Private K-12 Total	1-9	44,146		

Attachment 5-I (Continued)

Facility	Cell	Damage ($ thousands)	Damage Factor (D/RV)	Functionality (%)
College & Univ.	1	*	*	--
College & Univ.	2	*	*	--
College & Univ.	3	*	*	--
College & Univ.	4	91,486	0.079	17
College & Univ.	5	22,870	0.042	14
College & Univ.	6	78,897	0.049	19
College & Univ.	7	534,105	0.103	19
College & Univ.	8	*	*	--
College & Univ.	9	86,414	0.098	18
College & Univ. Total	1-9	813,772		
School Buildings Total	1-9	991,685		

* Negligible damage

Attachment 5-J

SPECIAL FACILITIES - DAMS AND TALL BUILDINGS:

DAMAGE AND 72-HOUR POSTEARTHQUAKE FUNCTIONALITY

Facility	Cell	Damage ($ thousands)	Damage Factor (D/RV)	Functionality (%)
Dams	1-2	11	0.004	72
Dams	3,4,6	46	0.013	71
Dams	5,7-9	38	0.005	69
Dams Total	1-9	95		
Tall Buildings	1-9	389,764	0.103	27

Attachment 5-K

SUMMARY OF DAMAGE AND

72-HOUR POSTEARTHQUAKE FUNCTIONALITIES EVALUATION

Facility Group	Damage ($ millions)	Damage Factor Range (D/RV,%)	Functionality Range (%)
Medical Facilities	96.5	2.1 -15.2	14 - 26
Transportation Facilities and Systems	70.8	1.0 - 8.9	47 - 100
Gas and Petroleum Fuel Utilities	6.2	1.6 - 12.1	47 - 95
Water and Sewerage Utilities	6.7	0.2 - 3.3	65 - 98
Electrical Power Utility	57.7	1.6 - 5.0	74 - 84
Communications Network	14.5	4.6 - 9.0	35 - 74
Emergency Public Facilities	9.7	3.3 - 14.4	16 - 26
Residential Building	2,500	2.3 - 10.0	57 - 62
School Buildings	992	0.7 - 15.5	11 - 19
Special Facilities:			
-- Dams	.095	0.4 - 1.3	69 - 72
-- Tall Buildings	390	10.3	27
Total	4,150		

Attachment 6
CASUALTIES FOR THE ENTIRE STUDY AREA

2:00 a.m.

Cell	Minor Injuries	Serious Injuries	Deaths
1	209	97	7
2	66	45	2
3	76	67	3
4	213	80	7
5	841	245	29
6	423	130	15
7	1,766	381	61
8	242	80	8
9	691	159	23
TOTAL	4,527	1,284	155

2:00 p.m.

Cell	Minor Injuries	Serious Injuries	Deaths
1	511	69	18
2	177	24	6
3	415	55	14
4	654	88	23
5	1,560	211	54
6	944	127	33
7	3,663	494	125
8	545	73	18
9	2,027	273	69
TOTAL	10,496	1,414	360

Attachment 6 (continued)

4:30 p.m.

Cell	Minor Injuries	Serious Injuries	Deaths
1	241	36	9
2	89	13	4
3	182	28	7
4	280	43	11
5	752	106	27
6	487	71	18
7	1,709	242	61
8	333	51	19
9	943	139	35
TOTAL	5,016	729	185

Attachment 7

CASUALTIES FOR SCHOOLS

Summary of Casualties for Private Schools (2:00 p.m.)

Cell	Minor Injuries	Serious Injuries	Deaths
1	19	3	1
2	6	1	0
3	0	0	0
4	50	7	2
5	82	11	3
6	20	3	1
7	84	11	3
8	1	0	0
9	62	8	2
TOTAL	324	44	12

Summary of Casualties for Public Schools (2:00 p.m.)

Cell	Minor Injuries	Serious Injuries	Deaths
1	88	12	3
2	45	6	2
3	38	5	1
4	88	12	3
5	253	34	9
6	56	8	2
7	220	30	8
8	3	0	0
9	152	21	5
TOTAL	942	128	33

Attachment 7 (continued)

Summary of Casualities for College and Universities (2:00 p.m.)

Cell	Minor Injuries	Serious Injuries	Deaths
1	0	0	0
2	0	0	0
3	0	0	0
4	58	8	2
5	14	2	0
6	29	4	1
7	333	45	11
8	0	0	0
9	53	7	2
TOTAL	487	66	16

Summary of Casualities for Schools (2:00 p.m.)

Cell	Minor Injuries	Serious Injuries	Deaths
1	106	14	4
2	51	7	2
3	38	5	1
4	196	27	7
5	350	47	12
6	105	14	4
7	637	86	22
8	4	1	0
9	266	36	9
TOTAL	1,753	237	61